Mixing, Internal Waves and Mesoscale Dynamics in the East China Sea

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LONG TERM GOAL

The long-term goal of our research program is to better understand and quantify relationships between mesoscale dynamics, internal waves, and turbulence in shallow tidal-affected marginal seas.

OBJECTIVES

The objectives of the second year of the project were: (i) to determine the characteristics of internal-waves in the East China Sea (ECS) and to delineate their generation mechanisms; (ii) to verify the hypothesis that the origination of high-frequency non-linear internal wave and/or solitary wave packets are related to a particular phase of the barotropic tide, especially the periods of low surface elevation in the central northern part of the ECS; (iii) to investigate whether the reversing and rotating barotropic tidal flows affect shear-generated turbulence in the bottom boundary layer and of the water column in different ways; and (iv) to study the influence of non-linear internal waves on turbulence in the pycnocline and in the benthic boundary layer.

APPROACH

1. Analysis of the field data obtained during two research cruises (March and December 2005) by the Ocean University of China (OUC) and a research cruise of the Korea Ocean Research and Development Institute (KORDI) in August 2005; the former was carried out along the northeastern coast of China whereas the latter was conducted between the Chejudo Island and the KORDI research platform in the central ECS.

2. Launching two new focused field campaigns in the ECS in August (KORDI, southwest of the Chejudo Island) and September (OUC, southern Yellow Sea and the Yangtze River shelf) of 2006 to obtain comprehensive data sets on the characteristics of internal waves, thermohaline fine structure and turbulence using the bottom-mounted ADCPs and an ADV; thermistor/conductivity chains CTR7 with 4-7 sensors deployed in the thermocline; microstructure profilers TurboMap and MSS60; and regular CTD surveys. The Chinese r/v Dongfanghong-2 and the bottom-mounted platform with a set of moored instruments are shown in Fig. 1. (The pictures of r/v Eardo and instrumentations used by Korean oceanographers are given in *Lozovatsky & Fernando*, 2005).

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a)

b)

Fig. 1: OUC: a) – R/V Dongfanghong-2,
b) – The bottom-mounted set of ADCP, ADV and other instruments.

WORK COMPLETED

Field Campaigns

Since the research cruise of OUC onboard R/V Dongfanghong-2 is underway at the time of the preparation of this report (on September 27, 2006), we plan to forward the cruise report to ONR as soon as it is available to us (no later than October 30, 2006). The joint work with OUC has been very productive during the past year, with a one-month visit of PI Lozovatsky to China in October 2005 and a reciprocal 3-month visit of Mr. Zhiyu Liu, a PhD student of the co-PI Prof. Hao Wei, to ASU. The Chinese collaborators have transferred the full set of data obtained during the two field campaigns in 2005 to the PIs. A significant part of this data has already been analyzed, and a manuscript (*Lozovatsky et al*., 2006) is nearly ready for submission to CSR.

A new cruise was conducted by KORDI during August 11 - 17, 2006 in the same region of ECS as the 2005 cruise. This year, however, the cruise had to be shortened due to arrival of typhoon Wukong. This cruise onboard of r/v Eardo was organized by the co-PI J.-H. Lee, and PI Lozovatsky, who participated in this field campaign.

The hydrographic survey (26 stations with CTD, TurboMap, and ship-mounted ADCP measurements, see Fig. 2a) provided information on mesoscale spatial variability of thermohaline structure in the region. A special targeted experiment was launched to capture several NLIW episodes (observed near the low tide in 2005) as well as the characteristics of turbulence generated therein. A high-resolution 600 kHz ADCP and a thermistor/conductivity CTR7 chain with 4 sensors were setup in the thermocline from the drifting ship to provide information on time/space variations induced by internal waves, simultaneously with detailed Turbomap measurements.

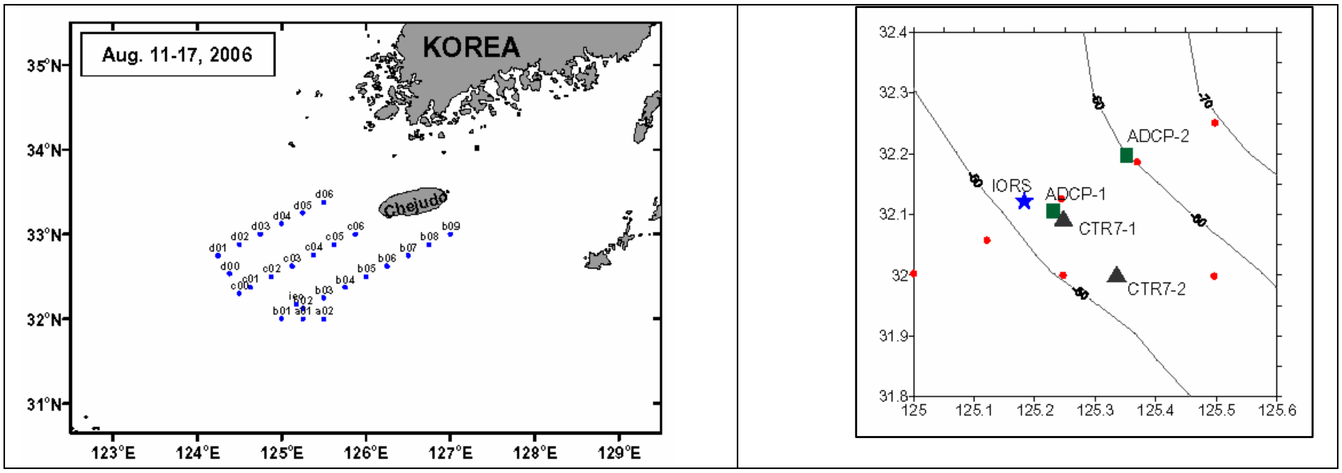


Fig. 2: a) - The region of hydrographic survey of the 2006 KORDI field campaign. The 25-hour drift station started near b02. b) - mooring locations of ADCP and CTR7 measurements.

During 25 hours (two M2 tidal cycles) of measurements at the drifting station, 164 Turbomap profiles were taken, thus enabling examination of IW-related variations of ε over the entire water column. A special mooring experiment that lasted 3.5 days included two bottom-mounted ADCP (300 kHz) and two CTR7 deployed 10 miles apart along and across the sloping bottom (Fig. 2b) to capture the NLIW propagation direction (*Lee et al.*, 2006). Separate sets of atmospheric and sea level data were obtained from the IORS research platform. Very light winds and extremely high air and sea surface temperature (SST > 30°C) isolated the interior layers of water from surface atmospheric fluxes, leaving tide as the major driver of internal-wave dynamics and vertical mixing. This makes the observations quite unique.

RESULTS

A. NLIW

Episodes of high-frequency internal waves, which lasted ~ 3 hours, were detected in the northern ECS during a specific phase of the barotropic tide (i.e., low tide at 32°N, 125°E). The observed internal waves (Fig. 3) influenced the entire water column. The wave packets were conceivably generated near the ocean shelf break, approximately 200 km to the southeast of the test site (Fig. 4). During several internal wave episodes, which coincided with the neap tide (Fig. 5), large-amplitude solitary wave-like features emerged preceding high frequency internal waves. Shear instability of the tidal current was explored as a possible mechanism for sustaining or regenerating internal-wave packets during the course of their propagation.

It was suggested that the rotating velocity field of tidal current may support sufficient vertical shear within the wave packets to cause outbreaks of K-H instability. These instabilities may gradually transition to more symmetric Hölmböe waves, following the increase of the bulk Richardson number.

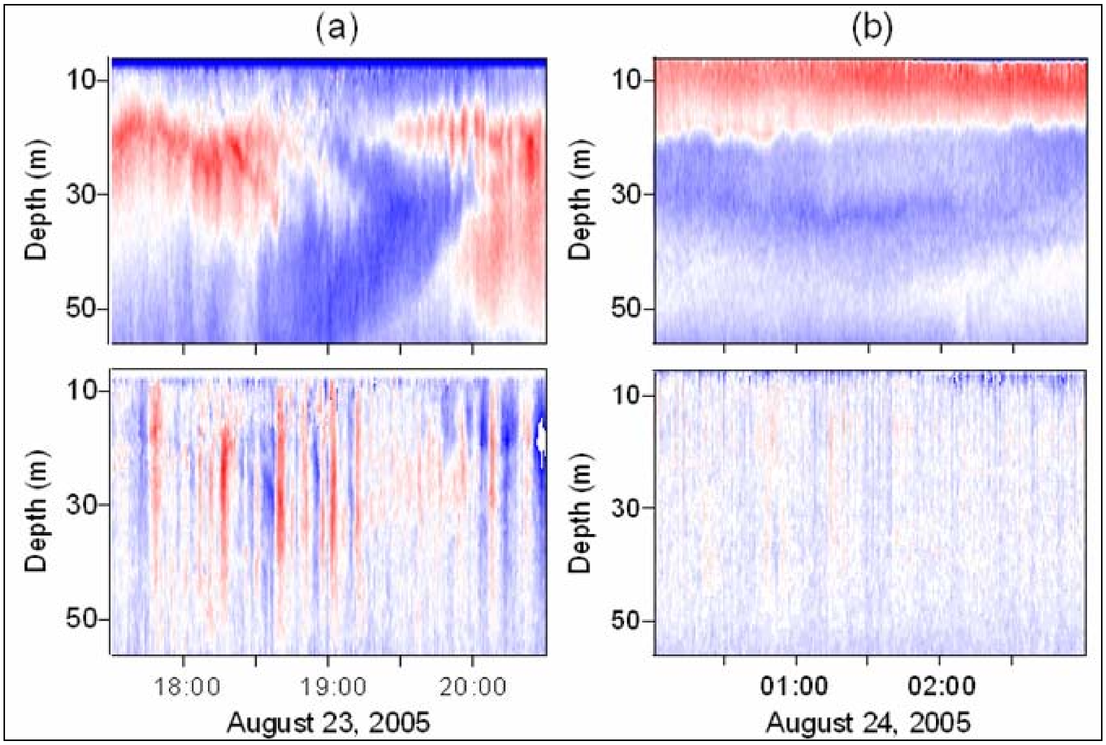
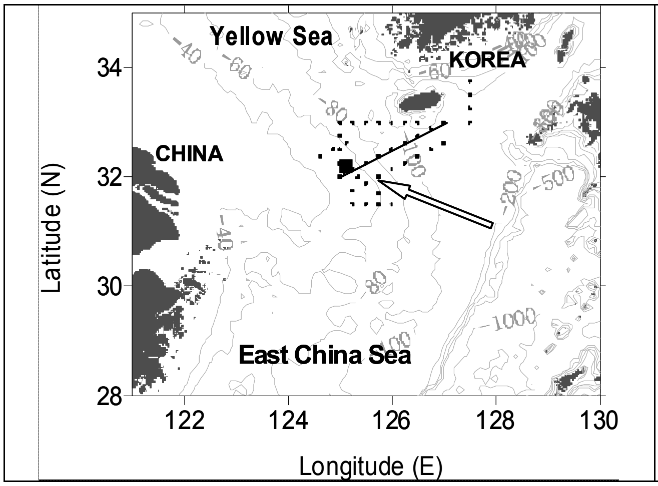


Fig. 3. An internal wave episode (a: 08/23/05) vs. a period of weak internal-wave activity (b: 08/24/05).



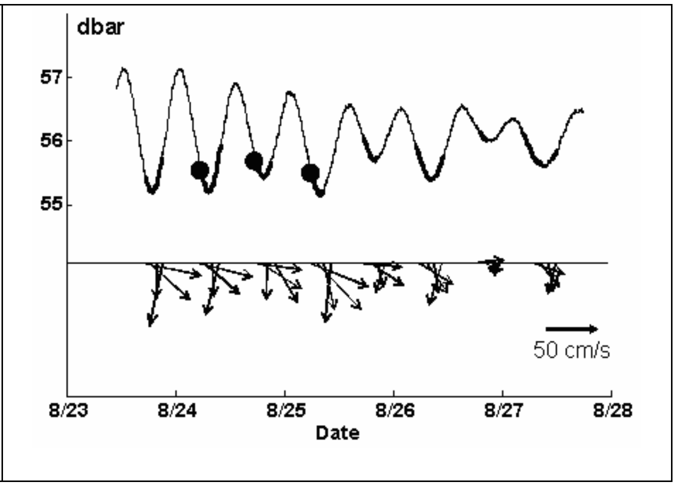


Fig. 4. Bottom topography of the northern East China Sea. CTD and Turbomap measurement sites (small circles) and ADCP/CTR7 moorings (large square) are indicated. The expected propagation of internal wave packets from the ocean shelf break is shown by the arrow.

Fig. 5 . A time series of the near-bottom pressure at the test site and the hourly-averaged current vectors for periods of low tide. The periods corresponding to the NLIW episodes are in bold. The cases where solitary waves preceded wave packets are shown by larger circles.

B. Turbulence

Reversing and rotating barotropic tidal flows affect, in different ways, the turbulent kinetic energy dissipation rate ε, friction velocity u_* and shear structure of the (i) lower part of the water column of the shallow inner shelf of China and (ii) water column over a deeper sloped bottom on an outer shelf, viz.,

(i) Vertical shear generated near the sea floor, slowly "propagates" to the water interior (Fig. 6), with a phase speed of ~ 5 m per hour, when the tidal vector rotates over a slopping bottom. In reversing tidal flow, the speed of shear propagation is 5-10 times higher.

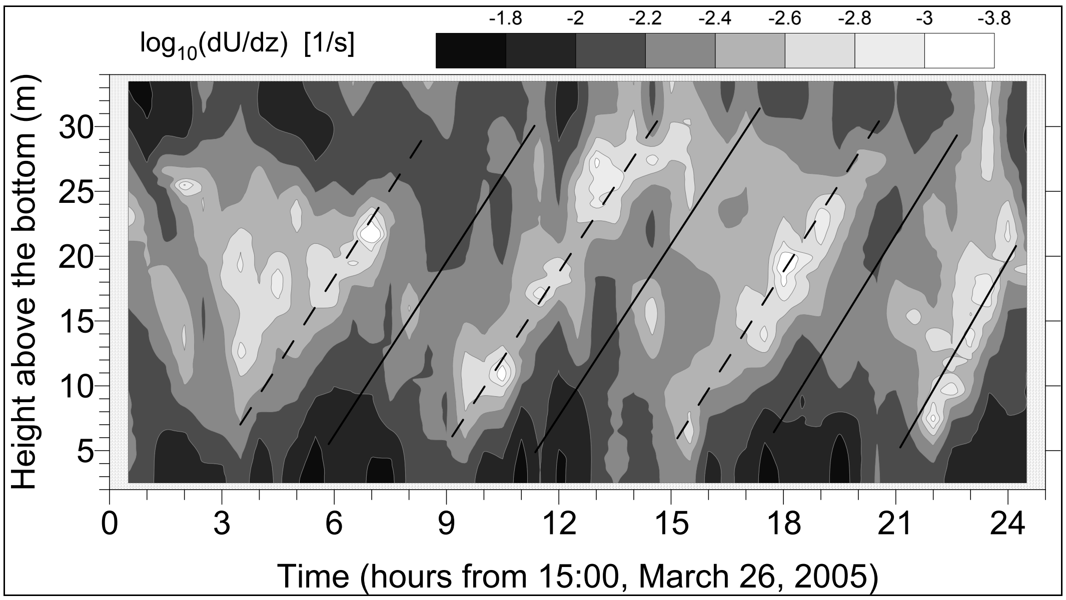
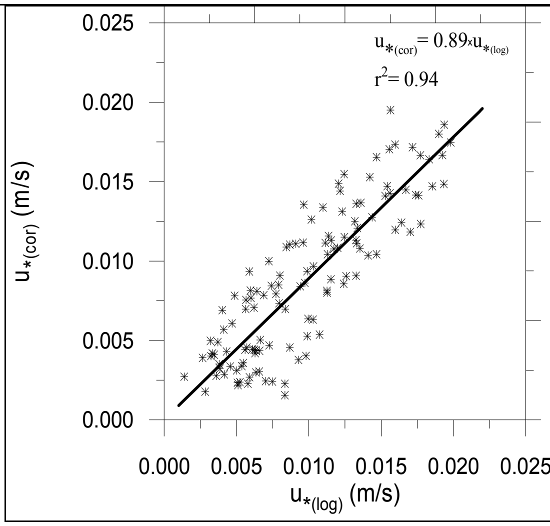


Fig. 6. Vertical shear is in rotating tidal flow. The phase shift for high-shear zones is shown by solid straight lines and for low-shear bands by dashed lines.

(ii) The log-layer estimates of u_* in the reversing flow exceed the skin friction layer u_* by less than 10%, on the average (Fig. 7), but this difference becomes ~ 100% when the tidal vector is rotating. The influence of the form drag and the rotation of velocity vector have been offered as possible reasons for this discrepancy.

(iii) The law of the wall for dissipation $\varepsilon = c_\circ u_*^3 / \kappa h$ based on the skin friction velocity is well satisfied for the case of reversing tidal flow, but for rotating flow the measured ε exceeded the u_*-based predicted dissipation rate by a factor of ~ 1.5.

(iv) The near-bottom turbulence on the inner Chinese shelf was found to be influenced by seiches generated in semi-enclosed bays. Seiche-related oscillations with a period of ~ 2.3 hrs were discovered near the Jiaozhou Bay, in addition to the barotropic reversing tidal flow signal. Substantial horizontal inhomogeneity of thermohaline variables as well as changes of the direction of the rotating barotropic tide led to periodic advection of warmer bottom water to the test site, triggering convective mixing and substantial increase of ε near the bottom. During such periods wherein both the bottom stress and convection dominate, substantial deviation from the law of the wall prediction was observed (Fig. 8, encircled samples).



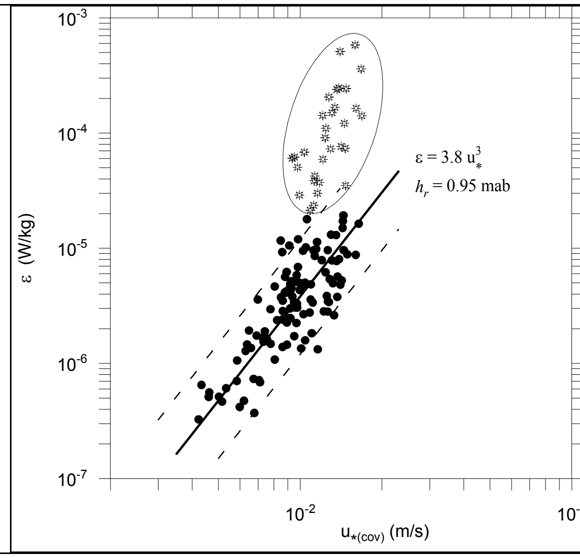


Fig. 7 . Regression between log-layer $u_{*(log)}$ (ADCP profiles) and near-bottom $u_{*(cor)}$ (ADV data) friction velocities in reversing tidal flow.

Fig. 8). The deviation from the law of the wall for rotating tidal current case. The samples that reflect a combined effect of the bottom stress and convection are encircled.

IMPACT/APPLICATION

Our research was greatly strengthened by the international collaboration with Korean and Chinese oceanographers. The PI I. Lozovatsky visited the Ocean University of China and delivered a series of lectures on marine turbulence. A Chinese PhD student, Zhiyu Liu and co-PI J.-H. Lee visited ASU in 2006 for collaborative research. The PI Fernando presented a series of lectures on mixing and internal waves at a Sumer School in Toulon (France) jointly with the Chinese co-Pi Hao Wei.

TRANSITIONS

None

RELATED PROJECTS

The Co-P.I. Fernando is involved in another ONR funded project dealing with laboratory investigations of waves in coastal zone, their breaking and interacting with solid objects. These projects are funded by Marine Geophysics and Coastal Dynamics Programs of ONR.

PUBLICATIONS

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